



Rationale for Missouri Lake Numeric Nutrient Criteria

December 2017

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1. Introduction

Nutrient pollution, or cultural eutrophication, is a pervasive and challenging issue that has impacted rivers, lakes, and oceans to varying degrees for decades. According to data queried from the U.S. Environmental Protection Agency (EPA), approximately 20 percent of current stream, river, and lake impairments nationally are attributed to nutrients or the impacts of nutrient pollution¹. Even though nutrients accounted for less than 10 percent of impairments in Missouri (MDNR 2016a), it is important to proactively develop protective procedures to guard against future degradation.

The primary mechanism of water quality impairment from nutrients is the growth of algae, which if left unchecked can result in several adverse consequences. These include reductions in dissolved oxygen caused by algal respiration and decay, unsightly blooms, reduced water transparency and, in some cases, the production of toxins by certain algae species, notably the blue-greens or cyanobacteria.

Parameters used to gauge the extent of nutrient impairment can be divided into two general categories: causal and response variables. Causal variables include the two nutrients that most commonly limit algal growth, total nitrogen (TN) and total phosphorus (TP); response variables include measurements of algal growth and water clarity. The most common method of estimating algal biomass is chlorophyll-a (chlorophyll), which measures the green photosynthetic pigments produced by algae. Water clarity is measured as Secchi disk depth.

The relationship between nutrient inputs and algal response is often difficult to define due to the influence of environmental factors including, but not limited to, temperature, amount and intensity of sunlight, mineral turbidity, depth of water body, water mixing depth, nutrient ratios, grazing, and competition. Furthermore, hydrologic and watershed factors such as precipitation, runoff, area, residence time, and land use complicate these relationships. Hydrologic and watershed factors are significant influences in all waterbodies, but are of particular importance to the water quality of rivers and lakes.

The majority of Missouri's lentic systems are man-made reservoirs. These water bodies differ from natural lakes in a number of ways that influence nutrient inputs and the response of algal growth relative to those inputs. These differences include: hydrology (water residence time), coupling with the watershed, sediment load, water level fluctuations, shoreline length, and potential for erosional inputs (Kalff 2002). While there are distinct differences between natural lakes and man-made reservoirs, the remainder of this document uses the term "lake" to describe Missouri's lakes and reservoirs for simplicity purposes.

An additional complicating factor in setting nutrient criteria is that suitable trophic conditions for supporting the various designated uses do not coincide, and are often at odds with each other. In particular, support of aquatic life depends in many situations on a relatively high availability of nutrients and chlorophyll to supply the food chain (Michaletz et al. 2012a; Downing & Plante 1993; Ney 1996). In contrast, the suitability of a lake for drinking water supply or recreational use is typically favored by lower nutrient and chlorophyll levels.

¹ US Environmental Protection Agency. Assessment and Total Maximum Daily Load Tracking and Implementation System (ATTAINS). (n.d.). Retrieved September 9, 2016, from <https://www.epa.gov/waterdata/assessment-and-total-maximum-daily-load-tracking-and-implementation-system-attains>

Two nutrient compounds are regulated by existing water quality standards: total ammonia-nitrogen is regulated due to its toxicity potential to aquatic life and nitrate-nitrogen is regulated due to drinking water supply impacts. However, TN and TP criteria have only been approved for a limited number of Missouri water bodies.

In August 2009, the Missouri Department of Natural Resources (Department) adopted statewide lake (reservoir) numeric nutrient criteria for TN, TP, and chlorophyll. At the time, no other state in the country had statewide lake numeric nutrient criteria for all three parameters. Missouri's 2009 criteria development approach was based primarily on hydrological factors, including depth (as approximated by dam height), hydraulic residence time, and watershed characteristics, as these factors have been shown to significantly influence Missouri reservoir water quality (Jones et al. 2011, Jones et al. 2008b).

Although EPA supports the adoption of nutrient criteria, particularly for both causal and response variables, they denied approval of a substantial part of the rule. In their disapproval letter, EPA (2011) concluded that the proposed criteria

- 1) Were not based on sound, scientific rationale because the rule package did not include the data and other necessary information to allow others to independently reproduce the values, and
- 2) The approach failed to demonstrate that the proposed criteria values were protective of designated uses as outlined in 40 CFR 131.6(b).

EPA (2011) suggested that when resubmitting the numeric nutrient criteria, the Department should include any raw data and statistical analyses used to develop the values. EPA also suggested that the Department develop a rationale using multiple lines of evidence to develop more robust set of numeric nutrient criteria, regardless of whether or not a similar, hydrologic-based approach was used.

In response to EPA objections, the Department convened a stakeholder process to address EPA's comments and revise Missouri's lake numeric nutrient criteria. In September 2011, the stakeholder group met to begin discussions. The stakeholders consisted of diverse representatives from the Department, municipalities, agricultural groups, environmental groups, consultants, and other public agencies, the Missouri Department of Conservation (MDC), the University of Missouri (MU), and EPA. Jones Aquatic Consulting, LLC, also served under contract with the Department to provide technical input in the development of recommended criteria. Over the course of the next several years, the stakeholder group met periodically in an effort to assist the Department in developing scientifically defensible lake numeric nutrient criteria.

The Department considered input from the stakeholder group and decided on an approach that provided for the most scientifically defensible protections for the underlying designated uses. That approach, which is based on EPA's bioconfirmation guiding principles (EPA 2013) and detailed throughout this document, does the following:

- Targets aquatic life protections,
- Focuses on the biological response,
- Considers ecoregional differences and existing trophic levels, and
- Supplements response impairment thresholds with conservative nutrient screening thresholds (NST) and biological assessment endpoints to better support determinations of impairment.

The Department reviewed several different sources of information to derive lake numeric nutrient criteria. These sources included

- Recent numeric nutrient criteria development activities in other states,
- Missouri-specific reservoir water chemistry data,
- Literature reviews, and
- Expert opinion.

This report is organized into seven sections (including this introduction). A brief description of the subsequent six sections is as follows:

Policy Considerations – This section addresses policy issues raised by EPA during the stakeholder process related to 40 CFR §§ 130.3 and 131.11.

National Overview – This section provides a national overview of lake nutrient criteria.

Missouri Nutrient Data – This section describes the Missouri specific reservoir water quality data used in this report.

Water Quality Patterns in Missouri - This section assesses relationships and patterns of Missouri reservoir data with respect to nutrients and algal chlorophyll.

Response Impairment Threshold Development - This section describes how chlorophyll response impairment thresholds were developed for aquatic life protections.

Nutrient Criteria Decision Framework Using a Bioconfirmation Approach - This section describes an assessment “gray zone”, as well as nutrient screening values and biological assessment endpoints that will supplement response impairment thresholds when impairment status remains unclear.

2. Policy Considerations

Throughout the stakeholder process, the Department sought technical and policy feedback on draft lake nutrient criteria from EPA. The Department shared draft criteria with EPA during the stakeholder process and in conference calls held on February 29 and March 21, 2016. The draft criteria shared with EPA at that time:

- Targeted aquatic life and drinking water designated uses,
- Focused on the biological response variable chlorophyll, and
- Supplemented criteria with screening values and weight of evidence analysis.

EPA commented on the Department's draft criteria during the stakeholder process and later formalized these comments in a letter dated May 12, 2016. EPA's letter expressed that "[p]ursuant to 40 CFR §§ 130.3 and 131.11, water quality criteria must be based on a sound scientific rationale and must contain sufficient parameters to protect the designated use." To address EPA policy issues related to 40 CFR §§ 130.3 and 131.11, the Department has structured the Missouri lake criteria as a decision framework that applies on an ecoregional basis. The decision framework integrates causal and response parameters into one water quality standard that accounts for uncertainty in linkages between causal and response parameters. The decision framework includes response impairment thresholds, nutrient screening thresholds, and response assessment endpoints. This framework appropriately integrates causal and response parameters and is based on the bioconfirmation guiding principles that EPA (2013) has suggested as an approach for developing nutrient criteria. The following sections address important policy considerations needed to develop sound nutrient criteria.

2.1. Protections for the Most Sensitive Use

Section 131.11(a) of the Code of Federal Regulations requires States to adopt water quality criteria to protect designated uses. For waters with multiple designated uses, the criteria shall support the most sensitive use. All reservoirs in Missouri's Water Quality Standards (WQS) regulation are designated for aquatic life protection (AQL), human health protection (HHP), whole body contact recreation (WBC), secondary contact recreation (SCR), and livestock and wildlife watering (LWW). A number of additional reservoirs are also designated for drinking water supply (DWS) (10 CSR 20-7.031). It was decided through a series of stakeholder discussions that were part of the Department's Water Protection Forum that the focus of revised numeric nutrient criteria development would initially concentrate on the AQL and DWS designated uses.

The initial recommendations for DWS criteria, based on analyses of the limited microcystin data in Missouri's lakes, along with review of disinfection byproducts information from Missouri drinking water treatment plants, led to a suggested chlorophyll response impairment threshold of 25µg/L for DWS. This value was greater than the suggested chlorophyll threshold value for AQL in both the Ozark Border and Ozark Highland regions, and only 5µg/L less than the recommended AQL threshold value for the Plains Region. Given that AQL was the most sensitive use (based on recommended criteria) in two of three regions, with the response thresholds for the two uses being similar in the third region, it was decided that the focus of the current effort would be AQL criteria.

Data continues to be gathered on algal toxins in Missouri reservoirs, with primary focus on microcystins (a common group of algal toxins). A second toxin (cylindrospermopsin) was monitored in addition to

microcystin during the 2017 summer season. Currently, the Department is in discussions with the University of Missouri Limnology Laboratory to also add saxitoxin and anatoxin-a analyses to the lake monitoring programs. These additional data will help clarify the extent of algal toxins in Missouri's lakes, and combined with continued improvements in our understanding of both the factors that drive toxin production and the efficiencies of treatment in removing algal toxins from source water, will allow the state to better address drinking water protection during a future rulemaking.

Research and information continue to develop at the national level with respect to nutrient impacts and criteria for the protection of recreational uses. Missouri intends to pursue numeric nutrient criteria for recreational designated uses during a future rulemaking. This effort will allow studies currently underway by EPA and others on the effects of cyanotoxins on recreational uses to mature, and for the state to conduct user perception surveys of algae by the recreating public.

2.2. Response Impairment Thresholds

EPA recommends that states adopt both *causal indicators* (the nutrients introduced to the system – especially TN and TP) and *response indicators* (those measures of biotic productivity and activity reflecting the enrichment of the system including chlorophyll) for nutrient criteria (EPA 2000). The Department's focus on the biological response variable, chlorophyll has subsequently raised comments by EPA. Federal water quality standard (WQS) regulations at 40 CFR 131.11 do not explicitly specify whether both causal and response indicators are required, but require that "[s]uch criteria must be based on sound scientific rationale and must contain sufficient parameters or constituents to protect the designated use." It also requires such criteria be based on "scientifically defensible methods."

While algal biomass, as estimated by chlorophyll, is correlated to TP and TN concentrations, the Department elected to focus on the biological response variable chlorophyll. The Department's decision to focus on chlorophyll is based on natural variation between causal and response variables, and ultimately the designated use, as there are multiple confounding factors. The link between nutrient sources and designated uses involves multiple steps (Figure 2-1). Whereas traditional stressors are typically directly toxic, nutrient over-enrichment effects are systemic. Additionally, biological responses to nutrients can vary based on site-specific factors. For example, flushing rates, which vary among reservoirs, may limit the impact of phosphorus loading on water column concentrations, which ultimately stimulate phytoplankton production (EPA 2000). Grazing pressure and mineral turbidity also serve as confounding factors.

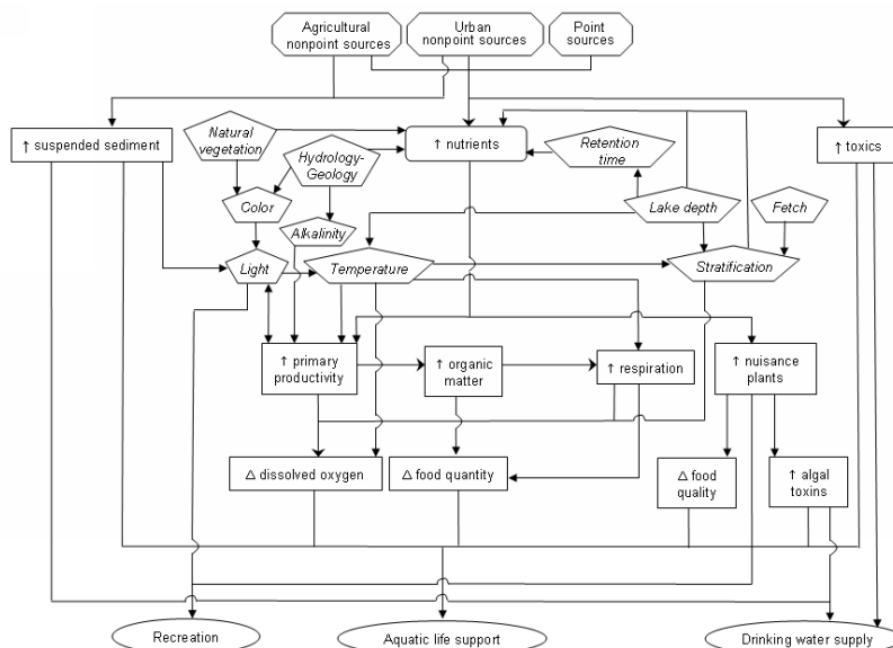


Figure 2-1. Conceptual Nutrient Model Diagram for Lakes from EPA 2010.

Chlorophyll is also more closely related than TN and TP to those factors that directly impact aquatic life uses, such as low dissolved oxygen and algal toxins. Additionally, because chlorophyll integrates the effects of TN and TP, it effectively serves as a site-specific indicator of trophic conditions. For these reasons, Missouri has chosen to focus on the biological response variable chlorophyll.

2.3. Purpose of Nutrient Screening Thresholds

In addition to chlorophyll response impairment thresholds, the Department is recommending the use of conservative nutrient screening thresholds (NST) for TN, TP, and chlorophyll to supplement response impairment thresholds described above. NSTs can be used to define the “gray zone” where impairment status remains unclear without a further weight-of-evidence evaluation. Results of this “gray zone” assessment can be used to identify reservoirs that are either impaired or those that should receive additional measures to prevent impairments from occurring. EPA’s primary comment regarding the use of screening values is that this approach seems to offer no protection beyond that provided under the state’s long-standing general (narrative) water quality criteria. Specifically, EPA suggested that screening values are reactive rather than protective, since actual impairments are required prior to listing as impaired.

NSTs are similar to other numeric thresholds, such as sediment probable effect levels, which are included in Missouri’s bi-annual 303(d) listing methodology document (LMD). The NSTs are intended to supplement chlorophyll response impairment thresholds and provide additional protections to Missouri reservoirs as follows:

- NSTs provide a quantitative metric for flagging reservoirs in need of additional evaluation. Threatened reservoirs that might otherwise go unnoticed are more likely to be identified and corrective measures can be taken earlier. This process also reduces the likelihood of false positive

impairment decisions that would direct the Department's limited resources away from restoration priorities.

- NSTs are set at levels considerably lower than the response impairment thresholds identified as protective of aquatic life.
- Exceedance of NSTs will also trigger a weight of evidence analysis to identify reservoirs that are impaired or expected to become impaired over the next five-year time horizon. As appropriate, these reservoirs may be assigned to Category 5 of the Department's Assessment, Listing, and Reporting categories (MDNR 2016a) to have a TMDL completed. Alternatively, these reservoirs may be assigned to Categories 4B or 5 Alt, which could trigger evaluation of appropriate, multi-disciplinary watershed management actions that can be implemented over time to prevent degradation of water quality. The Department will collaborate with other state agencies and stakeholders to establish these actions.
- The Department plans to search for all readily available data and information to make informed impairment decisions for lakes that exhibit water quality conditions within the "gray zone".

Further information and details on NSTs is provided in **Section 7**.

2.4. Protections for a Wide Variety of Biota

Missouri's designated aquatic life use definitions include protections for a "wide variety" of biota and federal regulations at Section 131.11(a) require that criteria protect the designated use. Like other states, (such as Virginia) the Department considers the status of the recreational fishery as an indicator of the reservoir's suitability for aquatic life (Virginia Water Resources Research Center 2005). However, EPA commented during the stakeholder process that this approach may not be protective of a "wide variety" of biota and suggested the Department consider a separate sport fish use. Based on EPA feedback, the Department conducted a closer evaluation of nutrient impacts on aquatic biota including mussels and non-sport fish species (see **Section 6**). The Department's findings show the health of sport fish populations can be interpreted as an indicator of overall ecosystem health and the presence a "wide variety" of aquatic biota, as defined in the existing regulation. This determination by the Department is consistent with the protection designation of aquatic life uses as defined at 10 CSR 20-7.031(1)(C)1, which states lakes and reservoirs will be designated based on limnological characteristics (such as temperature) and biological assemblages.

3. National Overview

Missouri conducted a review of lake nutrient criteria from around the country to help development of recommended criteria. Although EPA has stressed the need for adoption of numeric nutrient criteria on several occasions over the past few decades, currently only half of the states have either partial or statewide EPA-approved criteria (**Table 3-1**). Of those states with EPA-approved criteria, most include criteria for chlorophyll and/or TP. Only eight states have EPA approved criteria for TN.

EPA-approved lake nutrient criteria in a number of states target the response variable chlorophyll as the primary indicator of nutrient enrichment. States that have adopted lake or reservoir chlorophyll criteria as part of a response variable approach are described below.

- Alabama – Alabama applies chlorophyll criteria on a lake-specific basis, but lacks TP or TN criteria as described in the Alabama Administrative Code.

“The response to nutrient input may vary significantly lake-to-lake, and for a given lake year-to-year, depending on a number of factors such as rainfall distribution and hydraulic retention time. For this reason, lake nutrient quality targets necessary to maintain and protect existing uses, expressed as chlorophyll *a* criteria, may also vary lake-to-lake. Because the relationship between nutrient input and lake chlorophyll *a* levels is not always well-understood, it may be necessary to revise the criteria as additional water quality data and improved assessment tools become available” (AAC 335-6-10.11).
- Maryland – Maryland applies chlorophyll criteria to their Public Water Supply reservoirs, but has no reservoir criteria for TP or TN (COMAR 26.08.02.03-3).
- Minnesota – In Minnesota, an exceedance of TP ***and either*** the chlorophyll or Secchi disk transparency standard is required to indicate an impaired condition (Minnesota Administrative Rules 7050.0222).
- North Carolina – North Carolina applies chlorophyll criteria to Class C lakes and reservoirs, but has no criteria for TP or TN (15A NCAC 02B .0211).
- Oregon – Oregon applies chlorophyll criteria to all natural lakes and reservoirs to protect for nuisance phytoplankton growth. Lake TP criteria are currently limited to Clear Lake (Oregon Administrative Rules 340-041-0019).
- Texas – Texas applies site-specific chlorophyll criteria to reservoirs. TP and TN criteria do not apply (Texas Water Quality Standards §307.10).
- Virginia – Virginia applies site-specific chlorophyll criteria to reservoirs. TP criteria only apply if the reservoir received algaecide treatment during the monitoring and assessment period (9 VAC 25-260-187).

Table 3-1. States with EPA Approved Lake Nutrient Criteria.

State	Distribution	Chlorophyll (µg/L)	TP (µg/L)	TN (µg/L)
Alabama	Partial	5-27	--	--
Arizona	Partial	30-50	115-160	1,600-1,900
California	Partial	0.6-1.5	8-300	100-4,000
Colorado	Statewide*	8-20	25-83	426-910
Florida	Statewide	6-20	10-160	510-2,230
Georgia	Partial	5-27	0.5-5.5 lbs/acre-ft/yr	3,000-4,000
Illinois	Partial	--	50	--
Maryland	Partial	10-30	--	--
Minnesota	Statewide	3-30	12-90	--
Missouri	Partial	1.5-11	7-31	200-616
Nebraska	Partial	8-10	40-50	800-1,000
Nevada	Partial	5-45	25-330	250-1,000
New Jersey	Statewide	--	50-100	--
New Mexico	Partial	--	100	--
North Carolina	Statewide	15-40	--	--
Oklahoma	Partial	10	14-17	--
Oregon	Statewide†	10-15	241 lbs/yr	--
Rhode Island	Statewide	--	25	--
South Carolina	Partial	10-40	20-90	350-1,500
Tennessee	Partial	18	--	--
Texas	Partial	5-20	--	--
Vermont	Partial	--	10-54	--
Virginia	Partial	10-60	10-40	--
West Virginia	Statewide	10-20	30-40	--
Wisconsin	Statewide	--	5-40	--

Source: <https://www.epa.gov/nutrient-policy-data/state-development-numeric-criteria-nitrogen-and-phosphorus-pollution>

* Colorado labeled these values “interim” to emphasize its intent to undertake further review of the evolving science regarding nutrients before applying numerical standards broadly to surface waters throughout the state (EPA letter dated July 14, 2016 regarding EPA Action on Revisions to Regulation #31 Regarding Nutrients).

† Chlorophyll criteria apply statewide and TP criteria applies only to Clear Lake.

Other states have also adopted a response variable approach with additional weight of evidence procedures. For example, Arizona applies a weight of evidence approach contingent on chlorophyll values for identifying violations of narrative nutrient standards for lakes and reservoirs (**Table 3-2**).

Table 3-2. Arizona Weight of Evidence Approach for Identifying Violations of the Narrative Nutrient Standard for Lakes/Reservoirs.

Primary Decision Criteria	Weight of Evidence Supporting Criteria
1. The mean chlorophyll result is above the upper value in the threshold range	None needed.
2. The mean chlorophyll result is within the range, and	The mean blue-green result is at or above either blue-green threshold.
3. The mean chlorophyll result is within the threshold range, and there is additional evidence of nutrient-related impairments such as	Exceedances of DO or pH, or Fish kills attributed to DO or pH exceedances or ammonia toxicity, or Fish kills or other aquatic organism mortality attributed to algal toxicity, or Secchi depth below the lower threshold value, or Nuisance algal blooms present in the lacustrine portion of the lake or reservoir, or The upper threshold for TKN, TP, or TN is exceeded.
4. The mean chlorophyll result is within or below the range, but the lake is a shallow lake (mean depth less than 4m), and	Submerged aquatic vegetation is greater than 50 percent of the aerial extent of the lake bottom, and there is greater than 5 mg/L swing in diel (24-hr) DO measured within the photic zone (depth of light penetration supporting algal or plant growth).

Source: Adapted from R18-11-108.03 – Narrative Nutrient Criteria for Lakes and Reservoirs.

Note: EPA has not acted on R18-11-108.03.

Similar to Arizona, Maine has proposed a weight of evidence approach based on response indicators for its lakes and reservoirs (Chapter 583 Nutrient Criteria for Surface Waters (06-096 CMR 583 – Draft 6/12/2012). Under the Maine approach, compliance is determined by TP and any number of response variables including chlorophyll, Secchi depth, patches of bacteria and fungi, pH, dissolved oxygen, and aquatic life criteria. An affirmative impairment decision would not be made solely based on TP concentration; impairments would require exceedances of both the TP criterion and a response variable or a weight of evidence analysis of the response variables. This approach is not dissimilar to other states that take a response variable approach such as those previously described.

4. Missouri Nutrient Data

The Department used a robust dataset comprised of nutrient related measurements from over 200 reservoirs throughout the state to support the development of reservoir lake nutrient criteria. This dataset includes over 32,000 records of chlorophyll and nutrient data, making it one of the largest datasets used for criteria derivation. The data originated from various University of Missouri (MU) programs and special studies, but most notably from the Lakes of Missouri Volunteer Monitoring Program (LMVP) and the Statewide Lake Assessment Program (SLAP). The MU Limnology Laboratory, within the School of Natural Resources, oversees both of these programs, which are funded under CWA Section 319.

Both LMVP and SLAP collect water samples from Missouri's reservoirs for a variety of nutrient related measurements including algal chlorophyll, TN, TP, volatile and nonvolatile solids, and transparency (Secchi depth). The number of monitored reservoirs has varied over time, but LMVP samples approximately 66 reservoirs between four and eight times each year, whereas SLAP samples approximately 75 reservoirs four times each summer. SLAP employs students as field technicians to collect water samples and make field measurements while LMVP relies on citizen volunteers. Laboratory analyses for both programs are performed by the MU Limnology Laboratory. Monitoring protocols also differ between the two programs with respect to the length of the monitoring season, number of samples collected within the season, and the number of sites on individual water bodies. However, most all the data were collected during the summer growing season (May through September). Data collected outside of the summer growing season were not included in the database.

Data from the MU Limnology Laboratory were compiled into a database for analysis. Data were limited to sample sites located near the reservoir dam and excluded sites located in reservoir arms. Reservoirs were attributed in the database for geographic coordinates, size, Missouri water body ID, and ecoregion. The dataset included over 67,000 records from over 200 Missouri reservoirs spanning approximately 15 years (1999-2014).

5. Water Quality Patterns in Missouri

Data from the nutrient database were reviewed to characterize water quality conditions and patterns with respect to nutrients and chlorophyll across the state of Missouri. Unless otherwise noted, analyses were limited to data collected during the summer growing season (May through September) and years with at least four samples. Results from this evaluation are presented in the sections that follow.

5.1. Ecoregional Trophic Levels

Trophic state refers to the biological production, both plant and animal life, that occur in a lake or reservoir. All trophic classification is based on a division of the trophic continuum, of which there is no clear delineation of divisions (Carlson 1977). Reservoirs with low nutrient concentrations and low levels of algal production are referred to as oligotrophic, while water-bodies with high nutrient levels and productivity are termed eutrophic. Mesotrophic reservoirs fall in between oligo- and eutrophic on this continuum. Hypereutrophic reservoirs fall on the extreme high end of this continuum, and are characterized by excessive nutrients and are extremely productive in terms of algal growth. In these systems algal blooms may be frequent and severe. These blooms can lead to oxygen deficits when the bloom dies off and bacterial decomposition of the organic matter is maximized. Low oxygen concentrations can in turn negatively affect the aquatic life within the reservoir, causing reduced reproduction or lethality depending on the duration and intensity of dissolved oxygen decrease. Trophic state thresholds proposed by Jones et al. (2008a) for Missouri reservoirs are presented below in **Table 5-1**.

Table 5-1. Trophic State Thresholds for Missouri Reservoirs from Jones et al. 2008a. Values in parentheses represent the range of chlorophyll values reported for each trophic category worldwide (Nurnburg 1996).

Trophic State	Upper Limit of Chlorophyll for Trophic State (µg/L)
Oligotrophic	3 (2 – 4.3)
Mesotrophic	9 (5 – 10)
Eutrophic	40 (18 – 40)
Hypereutrophic	>40

The trophic state classification of eutrophic should not be confused with the concept of cultural eutrophication. Eutrophic is one of the four categories used by scientists and lake managers to place a water body within the productivity gradient. These categories are meant to be descriptive but not subjective in nature. Cultural eutrophication, on the other hand, is the process in which a water body becomes more productive due to human influences within the watershed. When cultural eutrophication causes a harmful change in water quality, it is considered to be undesirable. Also, cultural eutrophication can occur in all water bodies including oligotrophic systems.

There is a relationship between geographic location and the occurrence of trophic conditions in Missouri reservoirs (Jones & Knowlton 1993, Jones et al. 2008a, Jones et al. 2009). Reservoirs in the northern and western parts of the state (Central Dissected Plains and Osage Plain ecoregion) tend to be more eutrophic and hypereutrophic, while reservoirs in the Ozark Highlands ecoregion are generally mesotrophic and oligotrophic. Reservoirs in the Ozark Border ecoregion have a range of trophic states that are typically lower than the Plains ecoregion, but higher than the Ozark Highlands (Jones et al. 2008a). Regional patterns are apparent when evaluating long-term average chlorophyll concentrations calculated from the

updated Missouri dataset (Figure 5-1). These regional differences in water quality reflect geological, topographical and cultural land use differences across the state (Jones et al. 2008a, Jones et al. 2008b).

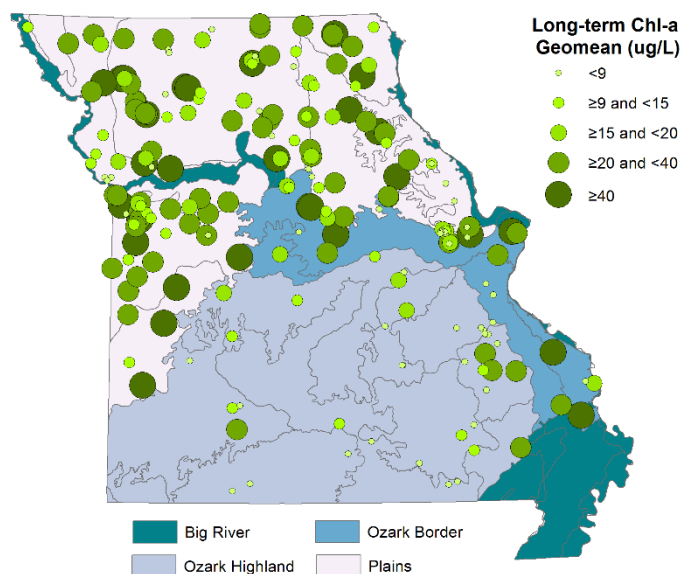


Figure 5-1. Long-Term Chlorophyll Geometric Means for Missouri Reservoirs.

Regional differences in trophic conditions are also apparent when seasonal average data are evaluated (Figure 5-2). In the Plains ecoregion, the interquartile range (25th to 75th percentile) of growing season chlorophyll levels are within the eutrophic zone of 10 to 40 µg/L. Growing season chlorophyll levels in the Ozark Border ecoregion are less than those found in the Plains ecoregion, as the interquartile range includes both the mesotrophic and eutrophic zones. Growing season chlorophyll levels are lowest on the Ozark Highlands where the median value of 5.8 µg/L is in the mesotrophic zone, with the interquartile range spanning from the oligotrophic to eutrophic zones.

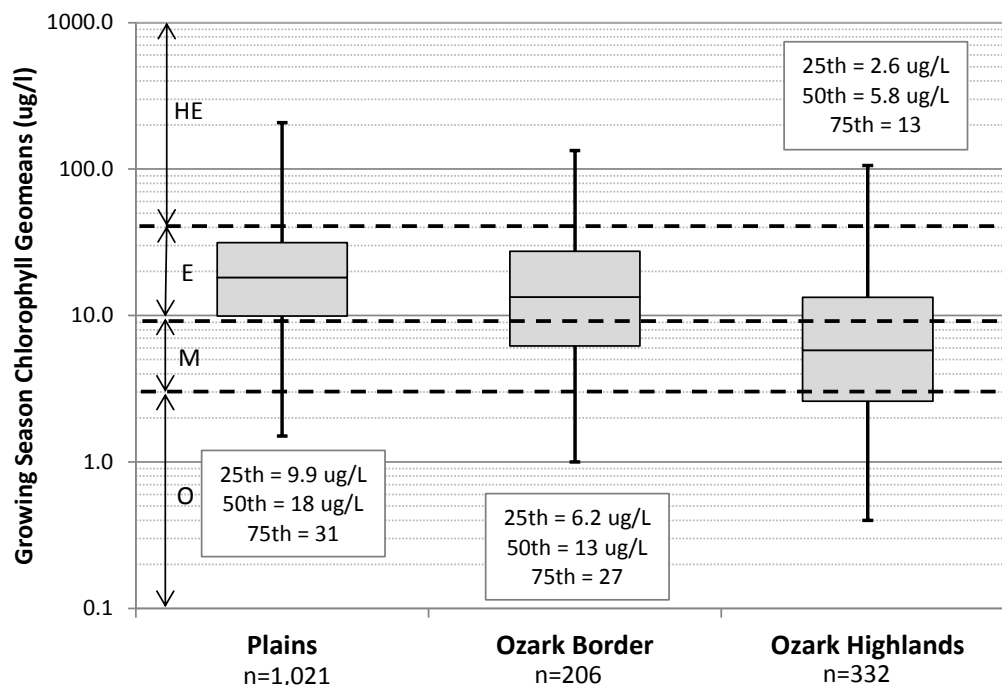


Figure 5-2. Distribution of Growing Season Chlorophyll Geometric Means by Ecoregion for Missouri Reservoirs.

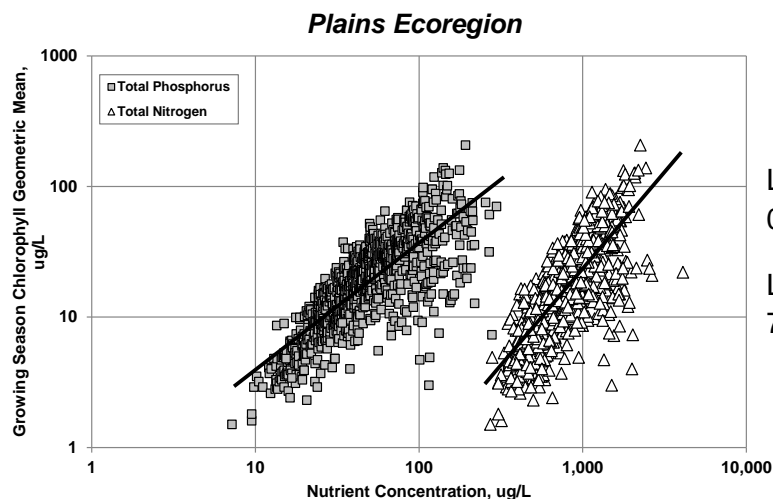
5.2. Nutrients

Empirical links between chlorophyll and TP have been extensively studied and are well defined (Dillon and Rigler 1974; Jones and Bachmann 1976), particularly in Missouri (Jones et al. 1998; Jones and Knowlton 2005; Jones et al. 2008a; Jones et al. 2008b), and therefore are not discussed here in detail. In Missouri reservoirs, TP accounts for 79 percent of the cross-system variation in chlorophyll. There is a 5-fold range of chlorophyll to TP ratios among long-term means indicating substantial variation in how the response variable, chlorophyll, relates to the causal variable, TP. Residual variation is likely due to reservoir-specific conditions including sediment influx (Jones and Knowlton 2005).

Relationships among chlorophyll, TN, and TP are evident in the Missouri data (Figure 5-3). The equations are expressed as ln-ln, which serves to normalize the data and provide the best basis for describing the relationship among these variables. The lognormal regressions yield R^2 values for TP ranging from 0.61 to 0.85 depending on the ecoregion. R^2 values for TN are slightly less, ranging from 0.56 to 0.79. Equations were generated from the regression analysis to estimate chlorophyll levels as a function of TP and TN.

Although chlorophyll data from Missouri reservoirs are strongly correlated with both TP and TN, studies suggest TN accounts for little variation beyond TP and unlikely serves as the limiting nutrient. For example, Jones and Knowlton (2005) show that in stepwise multiple regressions TP accounts for 60 percent of chlorophyll variation, while TN accounts only for an additional 1.8 percent of the variation. They further note that the relatively small variation in long-term average chlorophyll to TP ratios suggests that if nitrogen limitation occurs, it does not frequently depress biomass below expectations based on TP.

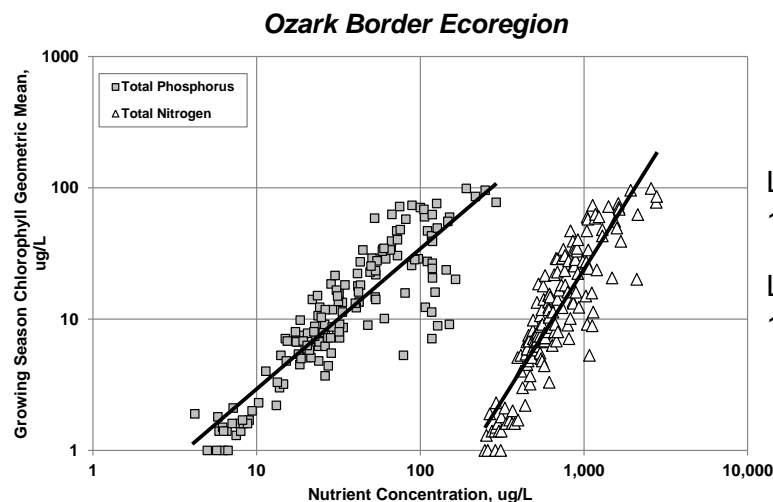
While **Figure 5-3** indicates a relationship between chlorophyll and both TP and TN, relationships between TP, TN and designated uses are less clear. As a measure of algal biomass, chlorophyll is more directly linked to aquatic life and recreational designated uses than either TP or TN. In addition to being one step removed from designated uses, the magnitude of the prediction intervals makes it difficult to precisely predict chlorophyll levels from TN and TP. This lack of precision makes TP and TN a less useful predictor of designated use attainment than chlorophyll.



Plains Ecoregion

$$\ln \text{ Chlorophyll} = 0.96 \ln \text{ TP} - 0.85 \quad r^2 = 0.61; n=975 \text{ (Eq. 1)}$$

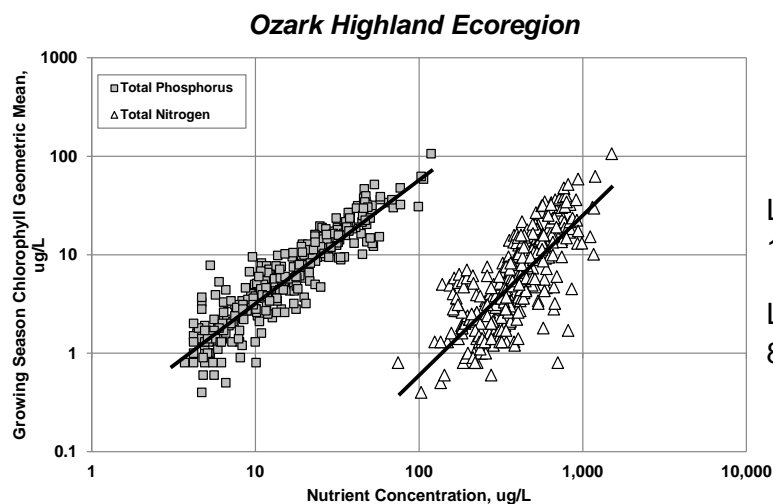
$$\ln \text{ Chlorophyll} = 1.48 \ln \text{ TN} - 7.08 \quad r^2 = 0.56; n=976 \text{ (Eq. 2)}$$



Ozark Border Ecoregion

$$\ln \text{ Chlorophyll} = 1.08 \ln \text{ TP} - 1.41 \quad r^2 = 0.79; n=158 \text{ (Eq. 3)}$$

$$\ln \text{ Chlorophyll} = 1.99 \ln \text{ TN} - 10.6 \quad r^2 = 0.79; n=158 \text{ (Eq. 4)}$$



Ozark Highlands Ecoregion

$$\ln \text{ Chlorophyll} = 1.27 \ln \text{ TP} - 1.70 \quad r^2 = 0.85; n=332 \text{ (Eq. 5)}$$

$$\ln \text{ Chlorophyll} = 1.63 \ln \text{ TN} - 8.01 \quad r^2 = 0.58; n=332 \text{ (Eq. 6)}$$

Figure 5-3. Relationships between Chlorophyll, Total Nitrogen, and Total Phosphorus in Three Missouri Ecoregions.

5.3. Temporal Variability

Scatter around the regression lines in Figure 5-3 demonstrates that factors other than nutrients influence algal response and resulting chlorophyll levels in Missouri reservoirs. These factors include physical, biological, and chemical attributes such as light limitation related to turbidity and algal self-shading, reservoir morphology, mixing status, hydraulic flushing rate², and zooplankton grazing (EPA 2000). In reservoirs specifically, factors related to hydrology substantially affect the variability in observed chlorophyll-nutrient relationships at any point in time.

Vollenweider (1975) showed that nutrient concentrations in reservoirs are directly related to inflow concentrations; as inflow concentrations increase, reservoir concentrations also increase. When these increases are coupled with high hydraulic flushing rates, reservoir nutrient concentrations are maximized (Welch and Jacoby 2004, **Figure 5-4**). In Missouri, in-reservoir nutrient concentrations effectively double when flushing rates increase from 0.25 to 2 times a year (Jones et al. 2008b). Jones and Knowlton (2005) further note that accounting for turbid inflow, as measured by increased non-algal seston levels, substantially decreases variability in chlorophyll-nutrient relationships. Turbidity has the effect of reducing chlorophyll:TP ratios due to poor light and high proportions of particulate, sediment-bound TP (Jones and Knowlton 2005).

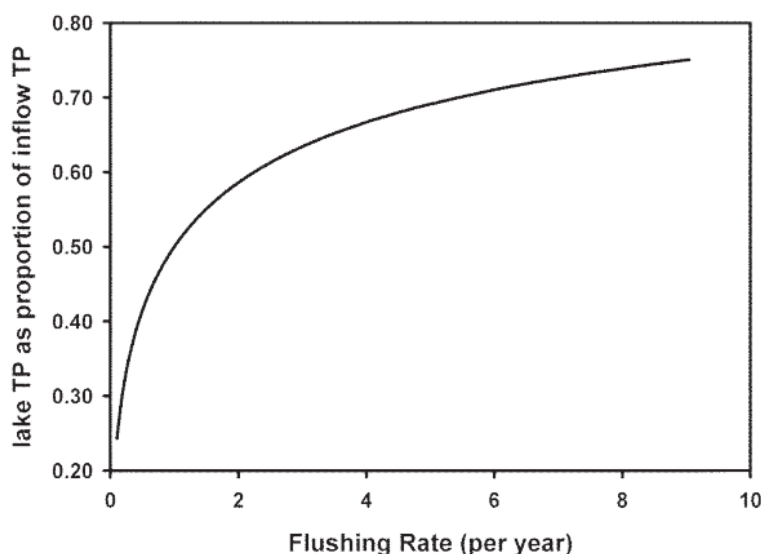


Figure 5-4. Estimated Relationship between In-Lake Total Phosphorus as a Proportion of Inflow TP to Flushing Rate from Welch and Jacoby 2004 as presented in Jones et al. 2008b.

The variability associated with these physical, biological, and chemical factors are not only apparent among reservoirs in Missouri, but also within specific reservoirs over time. For example, data collected

² Flushing rate is the number of times that a reservoir's entire volume will be completely renewed in one year. Flushing rate is related to hydraulic residence time (reservoir volume divided by reservoir outflow). For example, a reservoir with a flushing rate of 2 would have a hydraulic residence time of 6 months.

from Lake of the Ozarks between 1999 and 2014 demonstrate the variation that can be exhibited between samples from the same reservoir (Figure 5-5). Chlorophyll results measured over the sampling period average approximately 11 $\mu\text{g/L}$ but range from less than 2 to almost 45 $\mu\text{g/L}$.

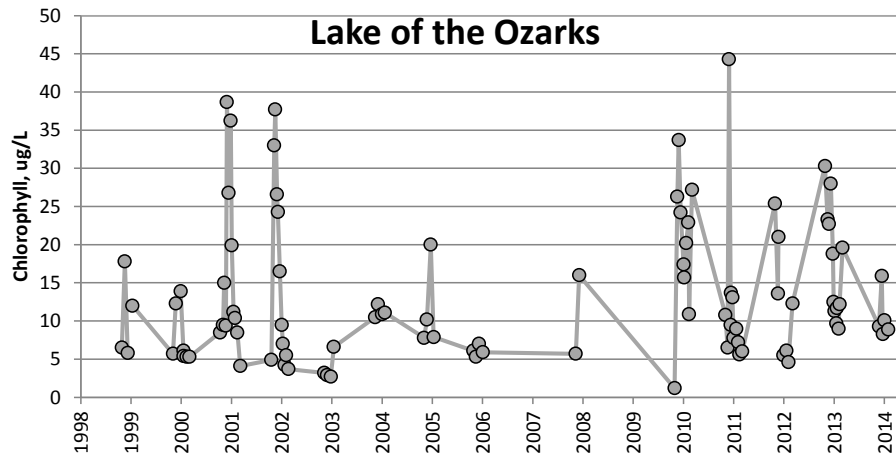


Figure 5-5. Discrete Chlorophyll Samples Collected from Lake of the Ozarks near the Dam between 1999 and 2014.

The impact of natural variability on observed chlorophyll and nutrient levels, empirical relationships, and trend detection has been studied extensively in Missouri reservoirs. Knowlton and Jones (2006a) found that seasonal average chlorophyll and nutrient levels in Missouri reservoirs can vary from year to year by a factor of 3 or more. Furthermore, they found that single season estimates incorrectly approximated long-term average values nearly 20 percent of the time (Knowlton and Jones 2006a). As a result of these findings, the researchers suggest using long-term average, rather than single season average concentrations, to evaluate the trophic status of reservoirs. These results demonstrate that applying criteria on an annual basis is a conservative management approach.

It is obvious from both scientific literature and the Missouri dataset that in addition to nutrients, physical, chemical, and biological factors play an important role in determining reservoir chlorophyll concentrations. These factors introduce substantial uncertainty into the process of investigating trophic status and must be considered when evaluating or applying empirical chlorophyll-nutrient relationships (Figure 5-3). To best reflect the current state of the science and our understanding of chlorophyll-nutrient relationships in Missouri reservoirs, the criteria development process must include provisions to account for uncertainty related to natural temporal variability.

6. Response Impairment Threshold Development

Establishing scientifically defensible lake nutrient criteria is challenging from a technical perspective, which is why progress has been limited since 1998 when EPA initiated the push for states to develop criteria. Aside from the complexities associated with variability in man-made reservoirs described earlier, nutrients are inherently non-toxic. In fact, phosphorus and nitrogen are nutrients that are essential for the growth and development of organisms. Unlike traditional toxics, lower levels of nutrients do not necessarily result in better attainment of designated uses. Furthermore, data are also currently insufficient to develop nutrient criteria for all designated uses in Missouri. For example, limited data are available that adequately link reservoir nutrient concentrations to risks associated with human health protection and fish consumption. Additionally, appropriate criteria for the protection of recreational uses are relatively subjective and have not yet been fully studied in Missouri. Further input is being sought from the public to determine what degree of water clarity is desired for suitability of this use.

EPA recommends the reference condition approach for setting criteria (EPA 2010). Reference conditions represent a “baseline that should protect the inherent beneficial uses of the nation’s waters” (EPA 2000). The rationale being that reference conditions “help to set the upper bounds of what can be considered the most natural and attainable lake conditions for a specific region” (*Id.*). However, use of reference conditions is better suited for natural lakes than man-made reservoirs because Missouri’s reservoirs were built long after large scale land-cover changes occurred on the landscape. Reservoirs are highly managed for purposes that may or may not be well aligned with expectations for a pristine, natural lake. Furthermore, nutrients in reservoirs are driven by human decisions such as dam height and watershed size, which depend on where the dam is built within the river valley.

Where reference sites cannot be identified, EPA suggests using the lower 25th percentile of data from a representative sampling of the entire population of lakes in an ecoregion (EPA 2000). However, this approach inherently assumes that all reservoirs are capable of achieving the same nutrient levels regardless of differences in factors such as watershed characteristics and flushing rates. It also presupposes that there is a link between designated uses and the 25th percentile value, which is not scientifically defensible and would not address EPA’s previous rationale rejecting the 2009 Missouri criteria. Additionally, it raises questions of policy because it effectively implies that 75 percent of lakes are impaired.

Given these issues, Missouri is recommending a tailored approach that focuses on evaluating the stressor-response relationships within a decision framework. Specifically, the Department has determined that chlorophyll serve as the basis for establishing response impairment thresholds. Response impairment thresholds are levels of chlorophyll above which the Department is confident that designated use impairment is likely and water quality restoration is needed. Chlorophyll was selected as the response impairment threshold parameter as it is the most common method of estimating the abundance of algae in a water body. Extreme, relatively high chlorophyll concentrations equate to excessive algal biomass, which is directly related to factors such as diurnal fluctuations in dissolved oxygen and pH that can directly affect aquatic life. Additionally, use of chlorophyll response impairment thresholds focuses efforts on the parameter that directly relates to impairments. This approach limits the challenges and uncertainties associated with implementing criteria based solely on causal indicators, which are strongly influenced by natural factors that increase variability and uncertainty.

The Department also recognizes inter-correlations such that TN and TP data serve a useful role in protecting Missouri reservoirs from cultural eutrophication. Therefore, as described in **Section 7**, TN and TP screening thresholds will be used to supplement chlorophyll response thresholds in identifying impairments.

Similar approaches have been adopted by other states. For instance, nutrient criteria for Virginia's reservoirs are limited to chlorophyll, unless the reservoir received algaecide treatment. Where causal variables are applied as criteria, some states apply stipulations. For example, Minnesota requires an exceedance of *both* TP and either chlorophyll or Secchi transparency. Similarly, Maine has proposed a decision framework whereby an exceedance of TP does not trigger an impairment decision unless there is additional evidence of impairment as measured by other indicators like chlorophyll or dissolved oxygen.

Missouri's recommended approach for reservoir nutrient criteria is intended to balance technical complexities with designated use protections by:

- Developing ecoregional response impairment thresholds,
- Focusing on the aquatic life designated use,
- Using conservative NSTs to identify reservoirs that do not exceed response impairment thresholds but may require additional evaluation of response assessment endpoints to determine if beneficial uses are not supported, and
- Using response assessment endpoints that outline narrative and numeric biological responses that are directly linked to designated uses. Exceedance of NSTs will also trigger a trend analysis (with consideration of hydrology) of historic data to identify reservoirs that are expected to become impaired over the next five-year time horizon. This trend analysis will be used to identify threatened reservoirs as impaired so that MDNR can take corrective actions.
- The Department plans to search for all readily available data and information to make informed impairment decisions for lakes that exhibit water quality conditions within the "gray zone".

Specific recommendations and the rationale for the aquatic life protection is described in the sections that follow.

6.1. Aquatic Life Use Response Impairment Threshold Recommendations

Missouri reservoirs are designated to one of the following AQL uses which are based on temperature and biological assemblages per 10 CSR 20-7.031(1)(C)1:

- *Warm Water Habitat (WWH) – Waters in which naturally-occurring water quality and habitat conditions allow the maintenance of a wide variety of warm-water biota.*
- *Cool Water Habitat (CLW) – Waters in which naturally-occurring water quality and habitat conditions allow the maintenance of a wide variety of cool-water biota. These waters can support a sensitive, high quality sport fishery (i.e., smallmouth bass and rock bass)*
- *Cold Water Habitat (CDH) – Waters in which naturally-occurring water quality and habitat conditions allow the maintenance of a wide variety of cold-water biota. These waters can support a naturally reproducing or stocked trout fishery and populations of other cold-water species.*

All three levels of AQL protections include provisions for the maintenance of a “*wide variety*” of aquatic biota. However, even though the relationship between species diversity/richness and productivity is well studied in ecology, the issue is still somewhat controversial (Mittelback et al. 2001). Review of the literature indicates a lack of consistency in how, or even if, productivity influences species diversity in aquatic systems. Factors not relating to productivity that can also influence species diversity include disturbances to ecosystem, grazing and predation, spatial scale of study, niche specialization by species, dispersal, and extreme environmental conditions (Fukami and Morin 2003, Declerck et al. 2005). “Productivity” can be measured in many different ways, and in the following section the term includes: potential productivity as estimated by nutrient levels, actual measures of biomass, and rates of carbon fixation. While the various studies use different measures of productivity, they are all related to primary production.

The influence of various factors can be seen in both laboratory experiments and field studies. Fukami and Morin (2003) investigated the influence of sequence of assembly in lab experiments using microbes. Results from their experiments indicate that intra-species interactions were important in shaping the relationship between productivity and diversity. Field studies such as those done by Chase and Leibold (2002), highlight the importance of scale on the relationship between species diversity and productivity. Invertebrate and macrophyte diversity were determined for 30 ponds located within 10 drainages (3 ponds per drainage). The diversity-productivity relation for this larger group of water bodies (n=30) was humped-shaped, with the highest diversity occurring in ponds with mid-level productivity. To examine diversity at the watershed scale, researchers combined the invertebrate and macrophyte data from the 3 ponds within each drainage and found a positive relationship, with highest diversity in the most productive drainages.

The species diversity-productivity relationship has also been investigated via large scale regional surveys. Jeppesen et al. (2000) looked at the species diversity of six different aquatic biotic groups across 71 shallow Danish lakes. The different aquatic groups displayed varying patterns of diversity relative to TP concentrations, with only the submerged macrophytes showing a strong negative relationship, likely due to light limitation, associated with increased algal biomass. The results suggest that there is no single level of productivity that can maximize diversity across the different aquatic biotic groups. The study also indicated that even hypereutrophic conditions (TP >400 µg/L) did not lead to large scale loss of diversity across six taxonomic groups.

A regional study encompassing 186 water bodies located within 8 states in northeast U.S. looked at diversity of benthic invertebrates, riparian birds, sedimentary diatoms, fish, planktonic crustaceans, and planktonic rotifers (Allen et al. 1999). Results showed that anthropogenic factors (human density in watershed) and measures of productivity (TP) had weak and varied influence on species diversity. For 5 of the 6 taxonomic groups, lake surface area was the strongest explanatory variable associated with species diversity (Allen et al. 1999). The authors noted that their results were consistent with those of Schindler (1987), who found assemblages were affected by only the most severe environmental perturbations.

Surface area was also the most important factor in predicting species diversity of crustacean zooplankton in 66 North American lakes (Dodson 1992). This study found 5 factors were significantly correlated to diversity: lake surface area (r-value = 0.75), mean depth (0.60), distance to nearest lake (0.57), number of

lakes within 20 km (0.56), and photosynthetic flux (0.50). These results highlight how important factors not relating to lake fertility and nutrient levels are in determining species richness in aquatic systems.

Mittelbach et al. (2001) reviewed 171 published scientific articles that investigated the diversity-productivity relationship, 55 of which dealt with aquatic systems. The authors divided the biota into three groups: fish, invertebrates and plants with 7, 28 and 20 published studies for each group, respectively (Table 6-1). A total of 19 of 55 studies (35%) showed no relation between species diversity and productivity, with only 4 of the studies (7%) having a negative relationship.

Table 6-1. Relationship between Diversity and Productivity for Three Different Aquatic Groups. Data represent information shown in Figure 4 of Mittleback et al. (2001).

Aquatic Group (# of studies)	Shape of Diversity-Productivity Relationship				
	Hump-shaped	Positive	Negative	U-Shaped	No Pattern
Fish (7)	3	2	0	0	2
Invertebrates (28)	11	2	3	2	10
Plants (20)	9	1	1	2	7
# of Studies (%)	23 (42%)	5 (9%)	4 (7%)	4 (7%)	19 (35%)

Another regional study found the diversity-productivity relationship to be complex with varying patterns for different aquatic groups as well as regional differences (Declerck et al. 2005). The authors concluded “Our results indicate that the search for a single diversity index aimed at assessing taxon richness at the level of the entire system on a regional scale is probably of low relevance” and that it might be best to “maintain a variety of lake types on a regional scale” to truly maximize aquatic diversity.

As indicated in Table 6-1, the literature suggests relatively higher nutrient concentrations support healthy fish communities (Knowlton & Jones 2003). Jones and Hoyer (1982) found a strong positive relationship between chlorophyll concentrations, up to 70 µg/L, and sport fish yields in Missouri and Iowa lakes. Michaletz et al. (2012a) reported that growth and size structure of sport fish populations increased with measures of water fertility, due to abundance of prey in more fertile water, but there is an upper limit beyond which fish population declines. While the positive relation between reservoir fertility (TP and chlorophyll) and game fish health exists, it is often secondary to inter- and intra-species interactions, indicating these systems are both complex and dynamic. Michaletz et al. (2012b) also reported that for largemouth bass and black crappie, fish size distributions had a threshold for chlorophyll of 40 to 60 µg/L, above which fish sizes declined. Additionally, largemouth bass and redear sunfish Catch Per Unit Effort (CPUE) were particularly low when TP exceeded 100 µg/L.

Downing and Plante (1993) used worldwide data to investigate the relation between lake fertility and fish production. They found a significant positive relation between fish production and both TP and chlorophyll concentrations. The results of this study, according to the authors, suggest that these systems operate “bottom-up”; with each trophic level in the aquatic food web being controlled by the subordinate level. The paper also notes that eutrophic lakes tend to have greater species richness, which leads to greater fish production when combined with the fertility potential of eutrophic systems.

Egertson and Downing (2004) reported that in Iowa lakes on a chlorophyll gradient of 10 to 100 µg/L, CPUE for common carp and other benthivore species increased. This pattern was partly at the expense of CPUE for more desirable species, notably bluegills and black crappie. While the declines of the latter

were not statistically significant, the results suggest that highly eutrophic conditions favor benthivores and disfavor piscivores, which are mainly visual feeders.

These patterns are consistent with results observed in other sport and non-sport fish populations. Ney (1996) reviewed data from reservoir studies and concluded that maximum biomass is supported at different TP levels for sport and non-sport fish communities. Using this information, Ney (1996) developed generalized relationships which suggest that sport fish biomass increases until TP concentrations near 100 $\mu\text{g/L}$; total fish biomass increases as TP approaches 300 $\mu\text{g/L}$ (Figure 6-1).

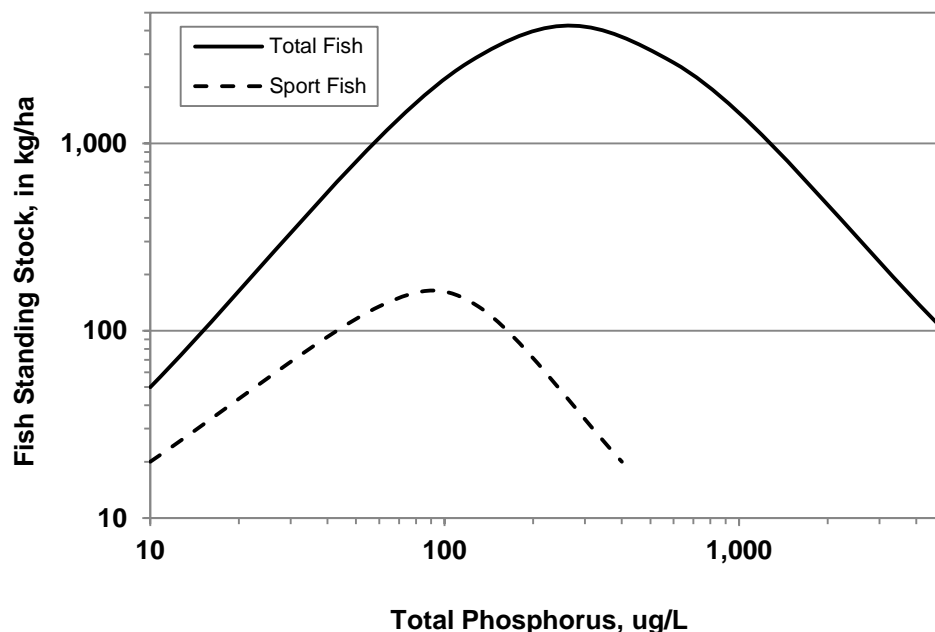


Figure 6-1. Generalized Relationship of Total and Sport Fish Standing Stock to Total Phosphorus Concentrations in Reservoirs Adapted from Ney 1996.

As has been demonstrated with fish communities, nutrient increases can also have competing positive and negative effects on other organisms, such as mussels. As nutrient levels increase, so does the abundance of mussel food sources, such as algae, bacteria, and fungi. Studies suggest that these increases create a beneficial, food-rich environment for mussel communities (Strayer et al. 2014). In cases of extreme eutrophication, changes in algal composition influence food quality and can impact habitat by reducing dissolved oxygen levels. In some instances, the release of ammonia by decaying algae following large algal blooms can also have toxic effects on mussels (Strayer et al. 2014). Nutrient poor environments however, may influence food availability and reduce mussel growth, abundance, and fecundity.

Nutrient thresholds at which positive and negative effects occur is largely unknown, because data are limited and impacts tend to vary by species. However, it is generally accepted that mussels exhibit a similar response pattern to increasing nutrients as fish (Figure 6-2). Mussel abundance (and likely diversity) increases in response to increasing nutrients because food availability and quality improve. At some upper nutrient threshold, which varies by species and is influenced by habitat and other physical and chemical waterbody characteristics, mussel communities decline (Strayer et al. 2014).

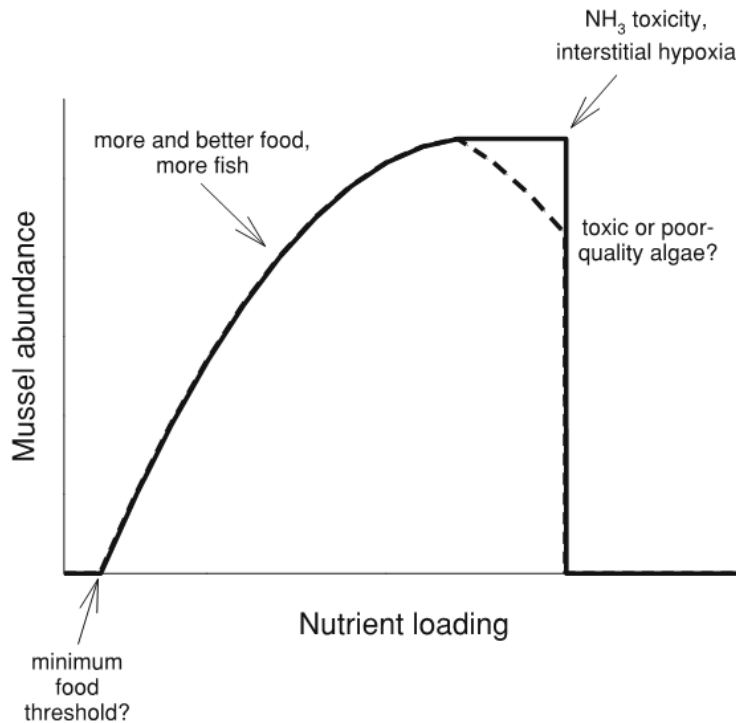


Figure 6-2. Generalized Relationships between Mussel Abundance and Nutrient Loading from Strayer et al. 2014.

As a group, mussels are some of the most imperiled aquatic organisms and reservoirs have had a negative effect on freshwater mussel diversity within the impounded drainages (Box and Mossa 1999, Watters 2000). The creation of a reservoir represents a loss of habitat, a change in sedimentation, and a shift in hydrology; all of these listed as being a greater stressor to freshwater mussels than nutrients (Richter et al 1997). Other problems for freshwater mussels associated with reservoirs include: deeper water that may not be tolerated by the mussels, cooler water temperatures in the hypolimnion which may reduce or eliminate reproduction, and the potential loss of the obligatory fish host required for mussel reproduction (Box and Mossa 1999, Watters 2000). Missouri's reservoirs are stressors on the freshwater mussel community within the state, and there is no evidence that nutrient reductions would have any positive effect on their recovery.

Overall, the literature suggests aquatic organism biomass and diversity generally increases with trophic state, but reaches some maximum level that varies across systems and aquatic communities. The literature also suggests that species composition may change across the trophic continuum. However, as EPA (2000) has pointed out, changes in biological structure alone are not sufficient indicators of nutrient impacts:

Unfortunately, changes in biological structure do not fit neatly into a nutrient-based classification because structural changes can occur along any environmental axis such as pH or temperature. The bioassessment of aquatic habitats has its strength in the concept that the organisms can be sensitive variables of the condition of the aquatic environment. However, unless a great deal is known about the requirements of the organisms

themselves, the assessment does not necessarily indicate the nature of the disturbance. Such general variables would be of little use as variables of nutrient change if they were susceptible to change by a large number of other factors as well.

In Missouri, data which help definitively characterize the structure, function, and diversity of all aquatic biota as related to nutrients in reservoirs is limited. However, Missouri sport fish data demonstrate that most reservoirs in Missouri provide water quality and habitat suitable for a variety of fish species. The Department maintains that using sport fishery status as an indicator of aquatic life use protection is ecologically justified because sport fish are generally apex predators in reservoir systems. The apex predators (top of the food chain) do not directly utilize the energy created by and stored within the algal community. Instead, the energy created via photosynthesis by the algae is passed upward through the aquatic food web via intermediate levels. A positive relation between algal biomass and the health of the apex predators requires these intermediate levels in the food web be present and functioning properly. Most Missouri reservoirs also support naturally-reproducing sport fish communities. Therefore, the health of sport fish populations can be interpreted as an indicator of overall ecosystem health and the presence a “wide variety” of aquatic biota, as defined in the existing regulations.

Following a review of the literature and discussions with Missouri reservoir and fishery management professionals, staff from MDC and MU made recommendations for chlorophyll concentrations that would support aquatic life uses in reservoirs (Table 6-2). The MDC and MU recommendation for the Plains is conservatively set to support sport fisheries rather than maximizing sport fish harvest. Using sport fishery status as an indicator of aquatic life use protection is ecologically justified because sport fish are generally apex predators in reservoir systems. Therefore, the health of sport fish populations can be interpreted as an indicator of overall ecosystem health and the presence a “wide variety” of aquatic biota, as defined in the existing regulations.

Ney (1996) reported that sport fish biomass peaks as TP nears 100 µg/L. According to the updated Missouri dataset presented previously (Figure 5-3), 100 µg/L is approximately 36 µg/L chlorophyll in the Plains ecoregion. For the Plains, MDC and MU suggested a more conservative value of 30 µg/L. For the Ozark Highlands, MDC and MU recommended a lower chlorophyll concentration of 15 µg/L, which reflects the regional pattern of reservoir fertility associated with the different physiographic regions of the state. The Ozark Border section represents a transition zone between the Plains and Ozark Highlands; therefore, MDC and MU recommended chlorophyll response thresholds intermediate to the other two sections. Missouri’s proposed chlorophyll response impairment threshold values are similar to EPA-approved criteria adopted in other states sharing Level III ecoregions with Missouri. West Virginia is in ecoregion XI, the same as Missouri’s Ozark Highlands, and has approved chlorophyll criteria of 10-20 µg/L. North Carolina is largely comprised of ecoregions XI and IX, similar to Missouri. North Carolina’s adopted chlorophyll criteria is 15-40 µg/L, again similar to Missouri’s proposed values of 15-30 µg/L.

Table 6-2. MDC and MU Chlorophyll Recommendations to Support Aquatic Life Uses.

Reservoir Ecoregion	Chlorophyll, µg/L
Plains	30
Ozark Border	22
Ozark Highlands	15

6.2. Response Impairment Threshold Recommendation Summary

After reviewing the scientific literature, Missouri reservoir data, and criteria development activities across the country, the Department has determined that chlorophyll should serve as the basis for response impairment thresholds in Missouri. Final recommended response impairment thresholds vary by ecoregion (

). The response impairment thresholds proposed in this document are intended to apply only to reservoirs at least 10 acres in size during normal pool conditions located outside the Big River Floodplain ecoregion. The 10 acre threshold was suggested in EPA's Nutrient Criteria Technical Guidance Manual (EPA 2000). It also reflects existing state regulations, which limit site-specific lake nutrient criteria to lakes larger than 10 acres outside the Big River Floodplain (10 CSR 20-7.031(5)N(2)).

Table 6-3. Final Ecoregional Chlorophyll Response Impairment Thresholds for Aquatic Life Beneficial Uses in Missouri.

Reservoir Ecoregion	Chlorophyll (µg/L)
Plains	30
Ozark Border	22
Ozark Highlands	15

Water quality criteria are expressed not only in terms of magnitude (allowable concentration), but also in terms of duration and frequency. Duration refers to the time period over which exposure is to be averaged. Specifying a duration is necessary because water quality naturally fluctuates in response to a variety of factors. The response impairment thresholds will be based on growing season summer average concentrations. Average growing season concentrations should be calculated as the geometric mean of a minimum of four samples per season. All samples must be collected from the reservoir surface, near the outflow end of the reservoir, and during the growing season of May through September. Criteria may be assigned at a later date to tributary arms of large reservoirs to provide additional protection.

Missouri researchers have shown that several years of data are necessary to accurately characterize reservoir chlorophyll conditions (Knowlton and Jones 2006b). Therefore, applying the criteria as single growing season, rather than long-term averages, is a conservative approach that is expected to provide sufficient protections for Missouri reservoirs. Frequency refers to how often the magnitude of the criterion may be exceeded. It is necessary to specify an allowable frequency because it is statistically impossible to project that criteria will never be exceeded. As ecological communities are naturally subjected to a series of stresses, the allowable frequency of pollutant-related stress should be set at a value that does not significantly increase the frequency or severity of all stresses combined (EPA 1994). EPA typically recommends an excursion frequency of not more than one in three years for most pollutants. The Department is recommending the same excursion frequency for its response impairment thresholds.

A summary of the lines of evidence used to develop the ecoregional response impairment thresholds is as follows:

- The Ozark Highlands are in the same ecoregion (XI) as West Virginia, where statewide chlorophyll criteria of 10 -20 µg/L have been approved by EPA (Table 3-1).

- The majority of Missouri's reservoirs are in ecoregions IX and XI, similar to North Carolina, where statewide chlorophyll criteria of 15 – 40 µg/L have been approved by EPA (Table 3-1).
- The relationship between aquatic diversity and productivity is mixed (Table 6-1). Setting criteria at moderate chlorophyll levels (15 – 30 µg/L) is a conservative approach.
- Research on relationships between game fish health and productivity in Missouri reservoirs suggest a positive relation up to 50-70 µg/L chlorophyll. Setting chlorophyll criteria at 15 – 30 µg/L is a conservative approach.
- Ney (1996) reports sport fish biomass peaks around 100 µg/L TP, which would result in a chlorophyll concentrations of 36 µg/L in the Plains Region of Missouri.

7. Nutrient Criteria Decision Framework Using a Bioconfirmation Approach

As described previously, the Department is recommending that the Missouri lake criteria be structured as a decision framework that applies on an ecoregional basis. The decision framework integrates causal and response parameters into one water quality standard that accounts for uncertainty in linkages between causal and response parameters. The decision framework includes response impairment thresholds, nutrient screening thresholds, and response assessment endpoints. This framework appropriately integrates causal and response parameters and is based on the bioconfirmation guiding principles that EPA (2013) has suggested as an approach for developing nutrient criteria.

In their discussion of bioconfirmation guiding principles, EPA describes the bioconfirmation approach “as an optional approach for developing numeric nutrient criteria (NNC) that integrates causal (nitrogen and phosphorus) and response variables into one water quality standard (WQS).” According to EPA, the bioconfirmation approach “seeks to address possible challenges in developing numeric N and P criteria in light of multiple factors (e.g., light, flow) that can influence ecological responses (e.g., algal biomass), and uncertainty around predicting N and P concentrations that adversely affect aquatic life.”

The concept of a “gray zone” has been widely discussed as an approach for addressing uncertainty around predicting nutrient concentrations that adversely affect aquatic life. In April 2013, EPA convened a workshop in which experts proposed the use of a “gray zone” to define a range, above which designated uses are impaired, and below which designated uses are attained. Nutrient levels that fall within the “gray zone” would be subject to a decision framework to combat the uncertainty around the relationship between nutrient concentrations and biological response (EPA 2014). Similar approaches have been proposed in other states including Virginia (AAC 2012) and Arizona (ADEQ 2008). MDNR supports the use of this decision framework approach.

The Department is recommending the use of the causal variables TN and TP along with chlorophyll for defining the low end of the “gray zone” as part of a holistic approach to reservoir nutrient management. These values, hereinafter referred to as nutrient screening thresholds (NST), define the low end of the “gray zone”. NSTs serve the purpose of defining the “gray zone” where impairment status is unclear without further evaluation and efforts may be needed to maintain the integrity of those waters.

Reservoirs that meet the applicable chlorophyll response impairment thresholds but exceed the NST for TP, TN, or chlorophyll fall into the “gray zone” and require a weight of evidence analysis (Figure 7-1). NSTs are similar to other numeric thresholds, like probable effect levels, that are included in Missouri’s LMD. NSTs help identify when a weight of evidence (WOE) analysis is needed based upon biological assessment endpoints.

7.1. Nutrient Screening Threshold Value Recommendations

Recommended NSTs for chlorophyll, TP, and TN are presented in

Table 7-1. Values are based on conservative assumptions designed to facilitate early identification of potential nutrient-related impairments that might otherwise go undetected. As with the recommended water quality criteria, NSTs represent growing season average conditions and should be calculated similarly.

Table 7-1. Nutrient Screening Thresholds.

Reservoir Ecoregion	NST, µg/L		
	TP	TN	Chlorophyll
Plains	49	843	18
Ozark Border	40	733	13
Ozark Highland	16	401	6

The basis for NSTs are described below.

- Chlorophyll NSTs were set equal to the 50th percentile of the distribution of growing season chlorophyll data for each ecoregion (Figure 5-2).
- TP and TN NSTs were back calculated using the respective chlorophyll NST and relationships presented in Figure 5-3.

7.2. Biological Assessment Endpoints

Consistent with EPA’s bioconfirmation approach (EPA 2013), the Department will evaluate biological assessment endpoints that fall in the “gray zone” described above. This evaluation will be based on quantitative analysis and expert opinion (e.g., state fishery biologists and water treatment specialists) to determine impairments. Reservoirs will be considered impaired if any of the following biological assessment endpoints indicate designated use impairment:

- Occurrence of fish kill events relating to excess algal production; Epilimnetic excursions from dissolved oxygen or pH criteria;
- Cyanobacteria counts in excess of 100,000 cells per milliliter (cells/ml);
- Observed shifts in aquatic diversity attributed due to eutrophication; or
- Excessive levels of mineral turbidity that consistently limit algal productivity during the period May through September.

According to the Missouri Department of Conservation’s (MDC) Fish Kill & Pollution Investigation Manual (MDC 2014), a fish kill is characterized by the death of a large number of aquatic organisms in a defined area over a short time period. Aquatic organisms include, but are not limited to, fish, amphibians, aquatic turtles, as well as invertebrates such as mussels, crayfish, mayflies and aquatic worms. Reported fish kill events trigger an investigation by MDC, which can involve the collection of water samples as well as a site evaluation. Through sampling and evaluation of the site, MDC can often determine the root cause of the kill event, including those related to excessive algal biomass (which can affect dissolved oxygen levels).

Lakes that exceed regional NSTs but are below the regional response impairment thresholds will be checked against MDC’s fish kill database to determine if a kill event related to eutrophication has occurred within the last ten years. A “small kill” event is defined as involving less than 100 fish, while a “large kill” is one that involves a greater number of fish or a larger area of impact (MDC 2014). It is recommended that a single “small kill” event (defined here as the death of <100 vertebrate aquatic organisms such as fish, amphibians, reptiles, etc.) should not be sufficient to be considered an

impairment. A reoccurrence of “small kill” events associated with eutrophication (2 or more within 10 years) however, would be considered evidence of impairment. A “large kill” event (≥ 100 vertebrate organisms) would only be considered as evidence of an impairment if the area affected was greater than 10 percent of the waterbody area; multiple “large kill” events that occur within a 10 year period would be considered an impairment regardless of area affected during the individual events.

During the 2017 monitoring season, the Statewide Lake Assessment Program began using YSI multi-sondes in the collection of lake profile data. Information collected via the sondes includes both dissolved oxygen (DO) and pH readings. These profiles are collected on each lake-visit, and are recorded electronically on the YSI handheld (and later downloaded to a laptop). The use of the YSI sondes will continue as standard data collection for the Statewide Lake Assessment Program.

Lakes that exceed regional NSTs but are below the regional chlorophyll criterion will have all recorded profiles checked for extremes in either DO or pH values within the epilimnetic layer of the lake. The lake will be considered to have an excursion if DO concentrations in the epilimnion were below 5mg/L. Excursions associated with pH will have occurred if readings in the epilimnion were less than 6.5 or greater than 9.0. The Department will use these data to identify impairments for these parameters as outlined in the LMD.

Along with monitoring nutrients and algal chlorophyll, the University of Missouri’s lake assessment projects also measure inorganic suspended solids (ISS). These materials, which are mostly soil particles from the watershed, can lead to light-limitation of algal biomass. Lakes with substantial levels of ISS often have chlorophyll concentrations that are low relative to the nutrient concentrations. Lakes with substantial ISS levels also often have higher nutrient levels as the watershed disturbances that lead to high ISS concentrations often also lead to elevated nutrient levels. A concern in these waterbodies is that a decrease in ISS levels due to sedimentation can lead to algal blooms, as the light environment improves and the algae are able to fully utilize the available nutrients. These bloom conditions can be detrimental to aquatic life as there are often fluctuations in both DO and pH associated with the increased levels of photosynthesis (more DO production and higher pH values), as well as a loss of DO when the bloom crashes and bacterial respiration increases.

Water quality from lakes that exceed regional NSTs but are below the regional response impairment thresholds will be reviewed to determine if light-limitation has consistently limited algal biomass. Those lakes that have a geometric mean ISS value $\geq 10\text{mg/L}$ (4 samples annually collected in at least 3 summer seasons of monitoring) will be identified. The chlorophyll to phosphorus ratio (CHL:TP) for these lakes will be calculated, first for each individual sample, with those ratios then being averaged. In Missouri’s lakes the median CHL:TP ratio (for individual samples) is 0.37 with an inter-quartile range of 0.24 – 0.55. Given these values, a lake that has an average CHL:TP value of 0.15 would be considered extreme. All lakes that have both an average ISS of $\geq 10\text{mg/L}$ and an average CHL:TP ratio of < 0.15 will be considered impaired.

Trend evaluations may also be used as part of a biological endpoint assessment. A critical consideration in implementing lake nutrient criteria is that the criteria protect against incremental deterioration of water bodies. Missouri’s antidegradation policy already provides such protections as it requires the maintenance and protection of existing water quality. However, determining whether or not water quality is

deteriorating requires a trend analysis. In the case of reservoir chlorophyll levels, a trend analysis must include a rigorous statistical evaluation based on a robust dataset.

The Department already incorporates provisions for conducting reservoir water quality trend analyses in their bi-annual 305(b) integrated water quality report (MDNR 2016a), which is reviewed by EPA. The Department generally uses linear regression to identify trends. Because identifying trends in reservoir water quality can be complicated by year-to-year variations, changing climate conditions, data limitations, and ecoregions, the Department suggests tracking reservoir trends on an individual basis for management purposes.

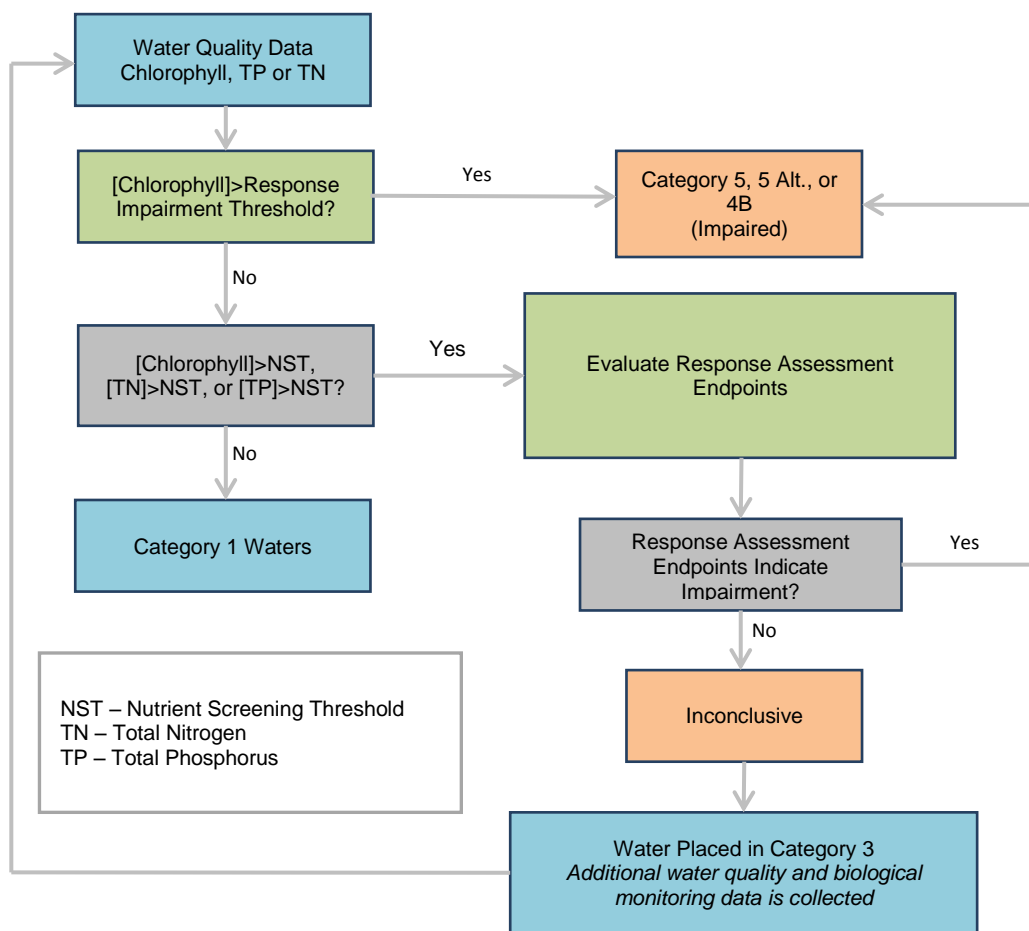
The Department also incorporates provisions for conducting trend analyses to identify threatened waters in the bi-annual 303(d) LMD, which is also reviewed by EPA. The most recent LMD states that time trend analyses should be used to identify waters that will not meet their designated uses before the next 303(d) listing cycle (MDNR 2016b). Recommended guidelines for conducting a trend analysis on chlorophyll levels are presented below:

- When evaluating trends, confounding, or exogenous variables, such as natural phenomena (e.g., rainfall, flushing rate and temperature) must be controlled for.
- The trend must be statistically significant. This process involves standard statistical modeling, such as least squares regression or LOcally WEighted Scatterplot Smoothing (LOWESS) analysis. To be considered statistically significant, the p value associated with the residuals trend analysis shall be less than 0.05.
- Impairment decisions based on trend analysis should, at a minimum, demonstrate that the slope of the projected trend line is expected to exceed the chlorophyll response impairment threshold within 5 years and that there is evidence of anthropogenic nutrient enrichment.

If the weight of evidence analysis suggests designated uses are being attained, the reservoir should be placed into Category 3A of the Department's Assessment, Listing, and Reporting categories (MDNR 2016a). If sufficient data are not available to adequately assess use attainment using the weight of evidence factors outlined above, the reservoirs should be placed into Category 3B so that these waters are prioritized for additional future monitoring. If the weight of evidence analysis demonstrates impairment, the reservoir should be placed into Category 5, 5 Alt., or 4B, as appropriate.

Table 7-2. MDNR's Assessment, Listing, and Reporting Categories.

Category	Description
Category 1	All uses fully maintained.
Category 2	At least one use has inadequate data to make a use attainment decision.
Category 2A	Available data suggest compliance with water quality standards.
Category 2B	Available data suggest noncompliance with water quality standards. High priority for additional monitoring.
Category 3	Inadequate data to make a compliance determination for all uses.
Category 3A	Available data suggest compliance with water quality standards. Lower priority for additional monitoring than 3B.
Category 3B	Available data suggest noncompliance with water quality standards. High priority for additional monitoring.
Category 4	Water quality standards are not attained but a TMDL is not required.
Category 4A	A TMDL has already been conducted.
Category 4B	Controls other than a TMDL will correct the impairment.
Category 4C	Impairment not caused by a discrete pollutant.
Category 5	A TMDL is required.
Category 5 Alt.	An alternative restoration approach is being pursued. Low TMDL priority.


Figure 7-1. Missouri Numeric Nutrient Criteria Decision Framework based on the Bioconfirmation Approach.

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